LET IT SNOW, LET IT FLOW: ASSESSING FUTURE CHANGES IN GREENLAND ICE SHEET RUNOFF USING MACHINE LEARNING AND CLIMATE MODELS

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DMI

WHAT IS ICE SHEET RUNOFF?

SURFACE MASS BALANCE & RUNOFF

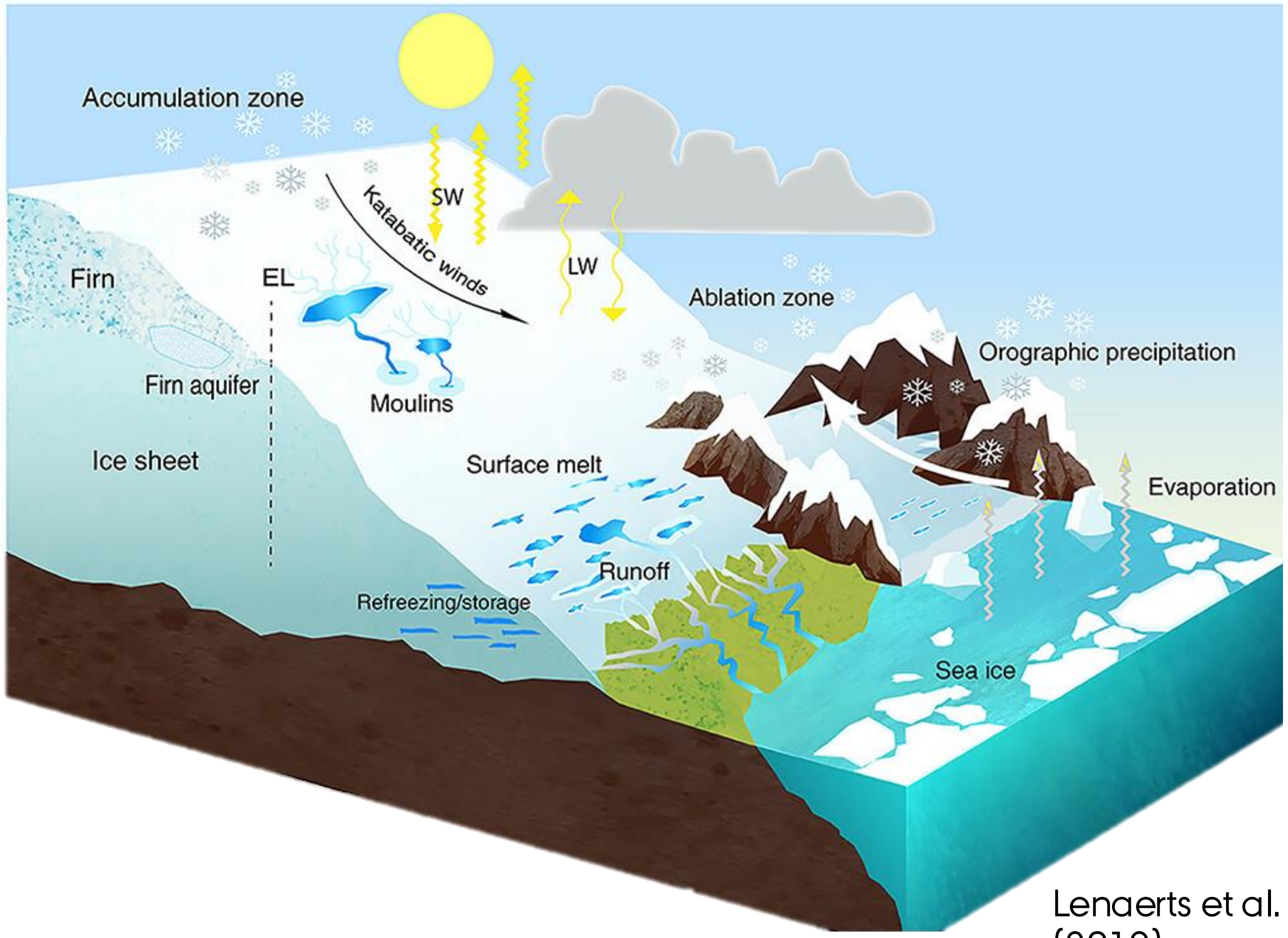
SMB = Precipitation
- Sublimation/Evaporation
- Runoff

Runoff = Rainfall
+ Surface Melt
- Refreezing
- Retention

from atmosphere

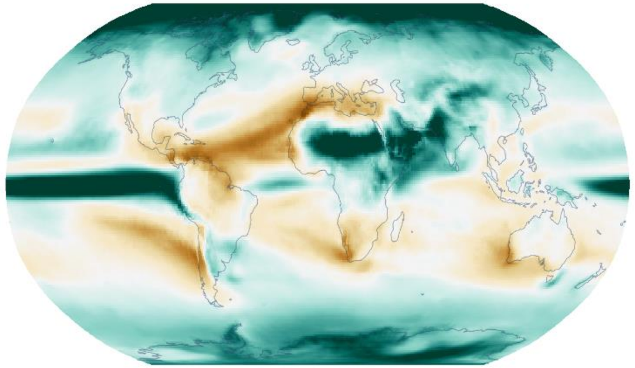
both

within the snow/firn pack

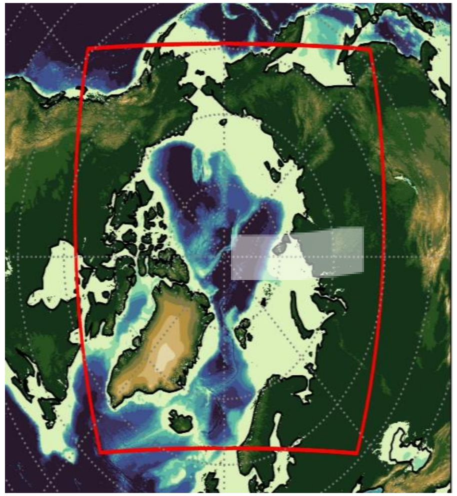


Lenaerts et al. (2019)

POLAR REGIONAL CLIMATE MODELS

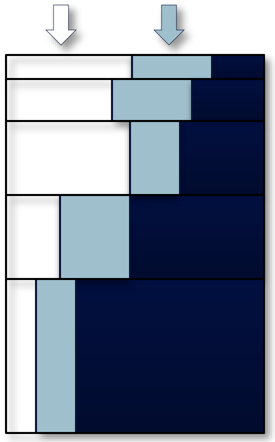


Input: atmospheric data from GCM

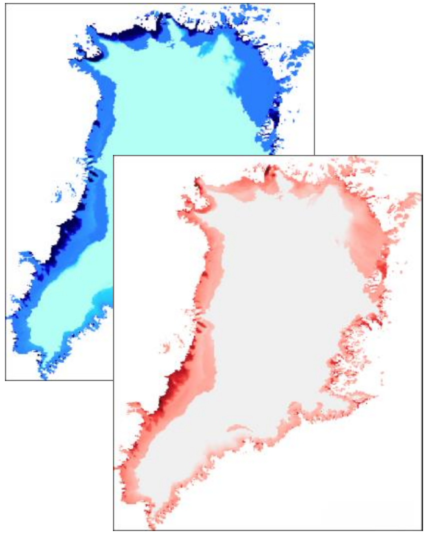


(a) atmospheric model

+



(b) firn model



SMB outputs (surface melt, albedo, runoff, refreezing, …)

WHY USING MACHINE LEARNING?

WHAT DO WE WANT?

RCMs are computationally expensive…

… want to emulate polar RCMs to

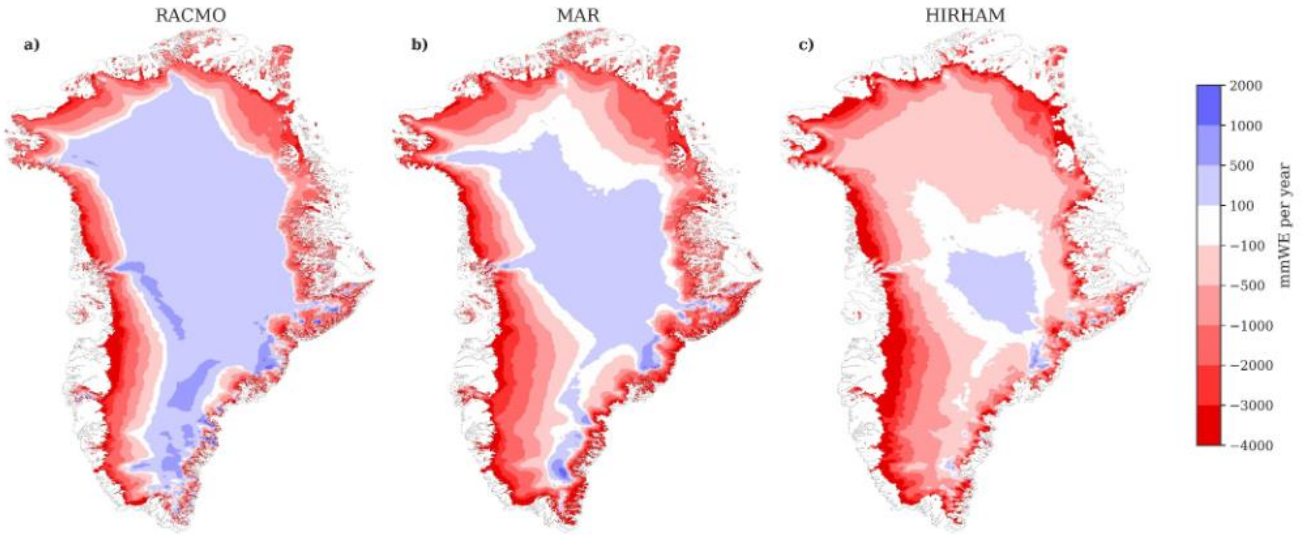
→ predict daily runoff

→ build large ensembles for SMB

→ explore dynamic topography

→ run sensitivity studies

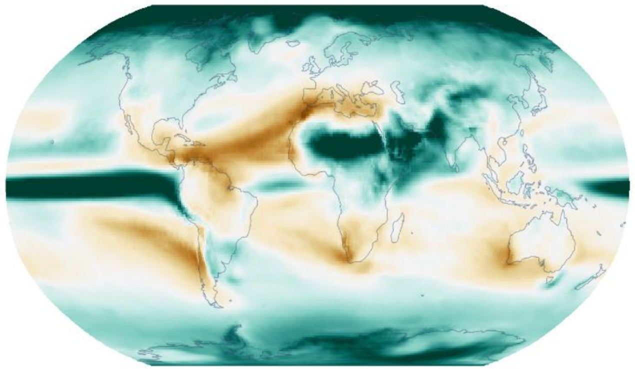
→ integrate into ESMs



Discrepancies in SMB projections from different polar RCMs (Glaude et al. 2024)

HOW TO USE MACHINE LEARNING?

POLAR REGIONAL CLIMATE MODELS



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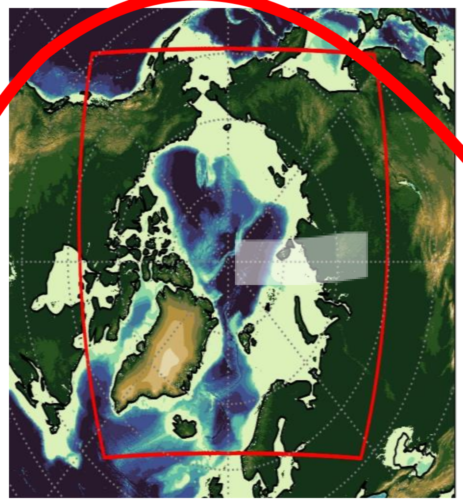

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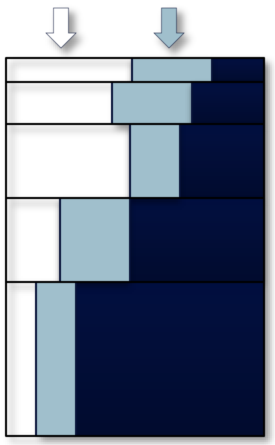
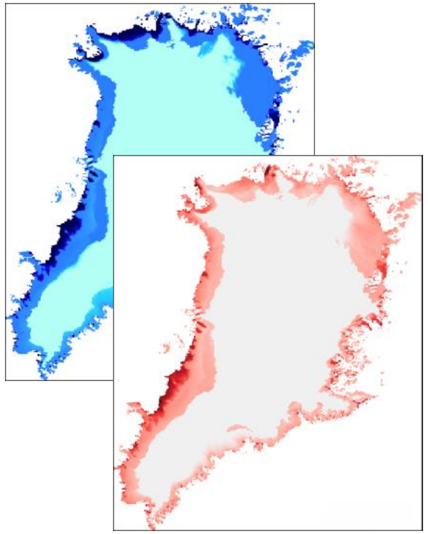


(b) firn model

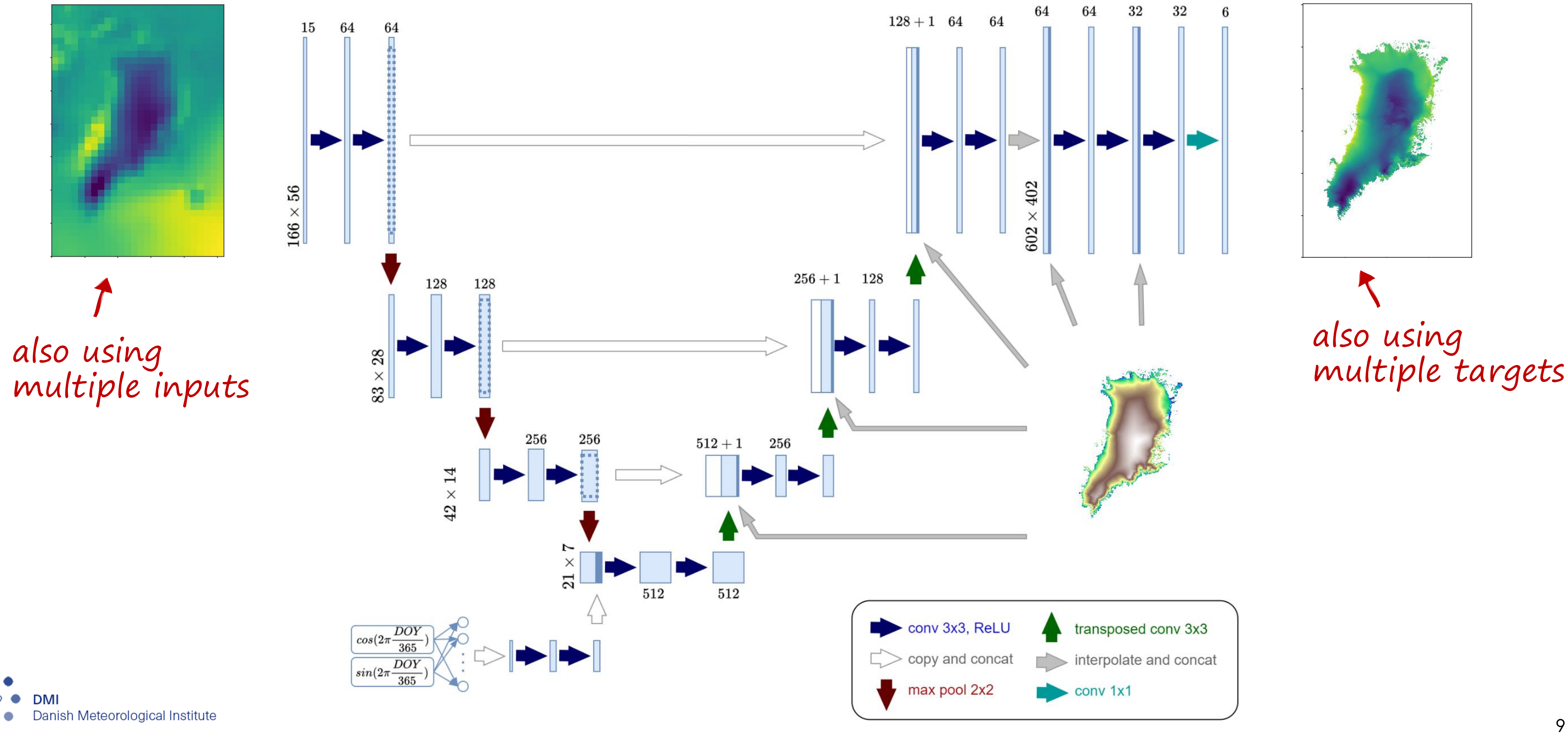
for ML: a spatial problem!

for ML: a temporal problem!



SMB outputs (surface melt, albedo, runoff, refreezing, ...)

UNET FOR ATMOSPHERIC DOWNSCALING



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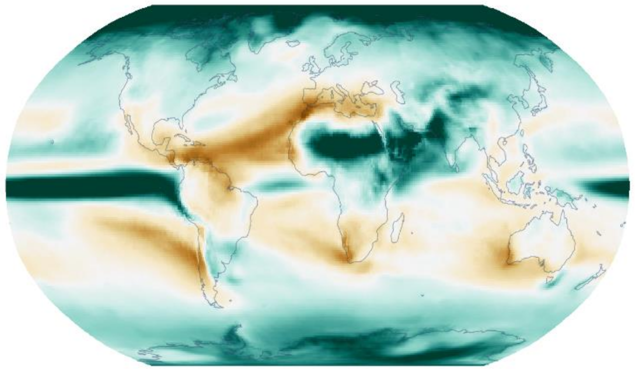
Danish Meteorological Institute

POLAR REGIONAL CLIMATE MODELS



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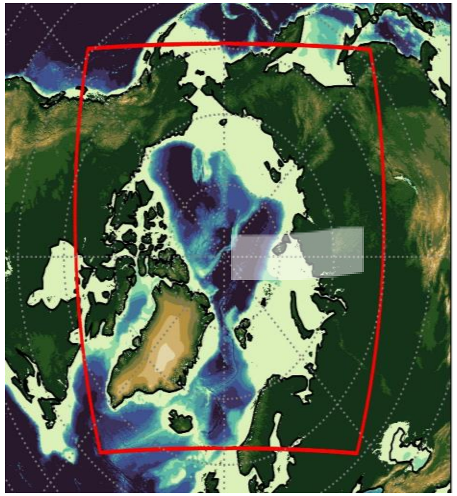

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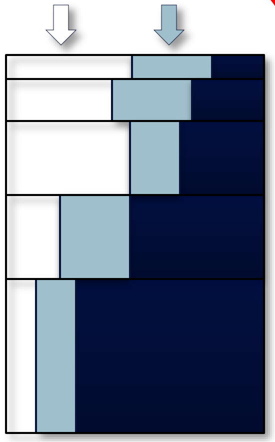

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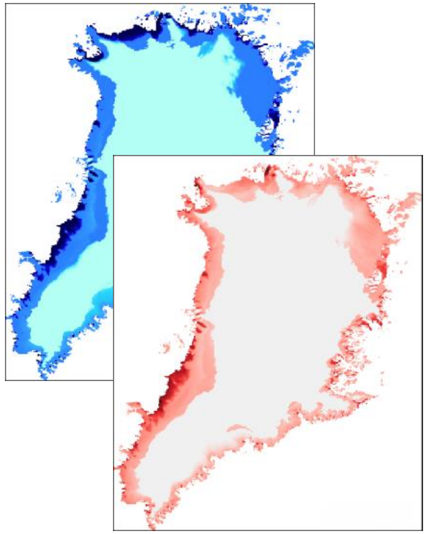
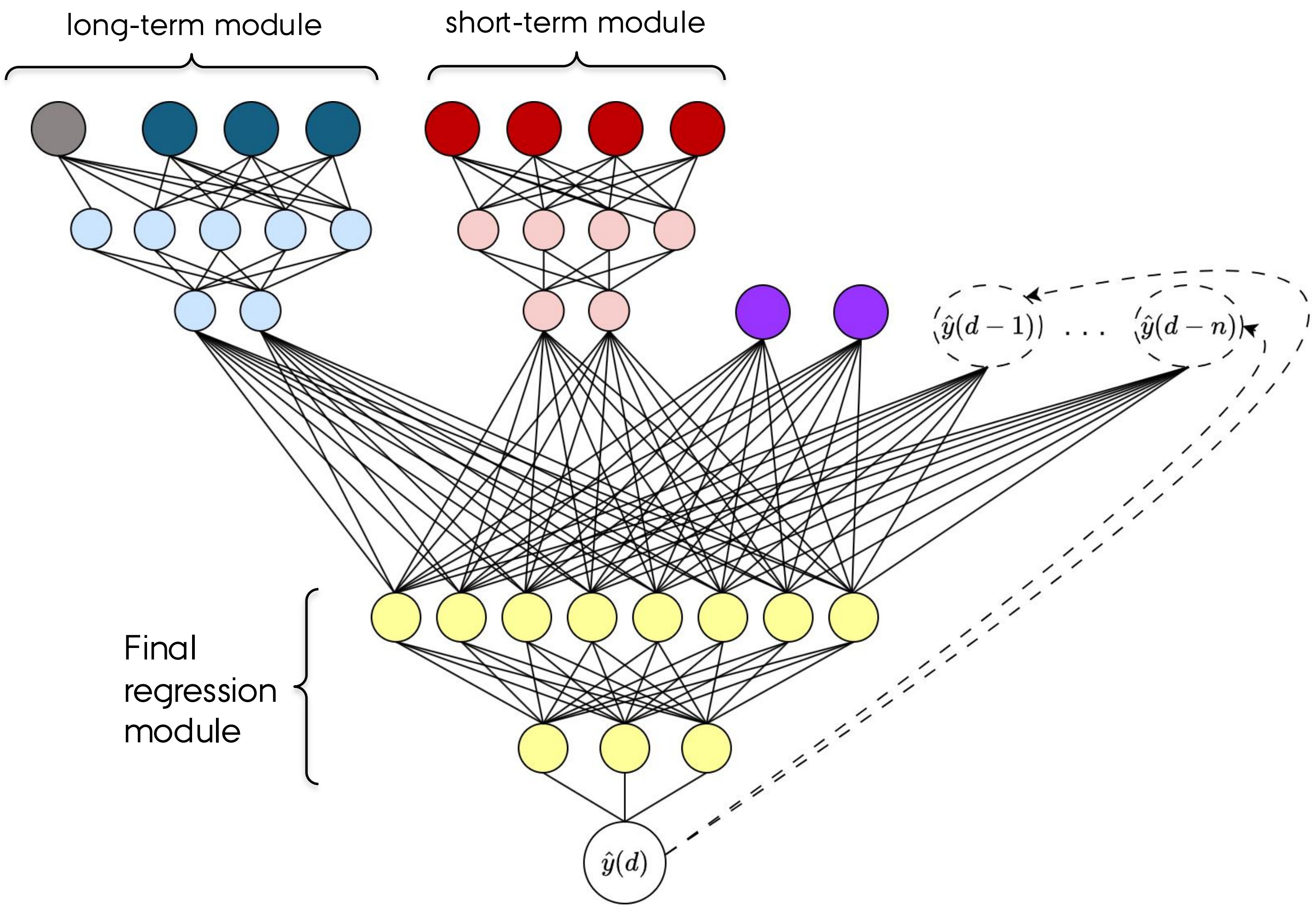


SMB outputs (surface melt, albedo, runoff, refreezing, ...)

for ML: a spatial problem!

for ML: a temporal problem!

A MODULAR NEURAL NETWORK



CHALLENGES

Which variables?

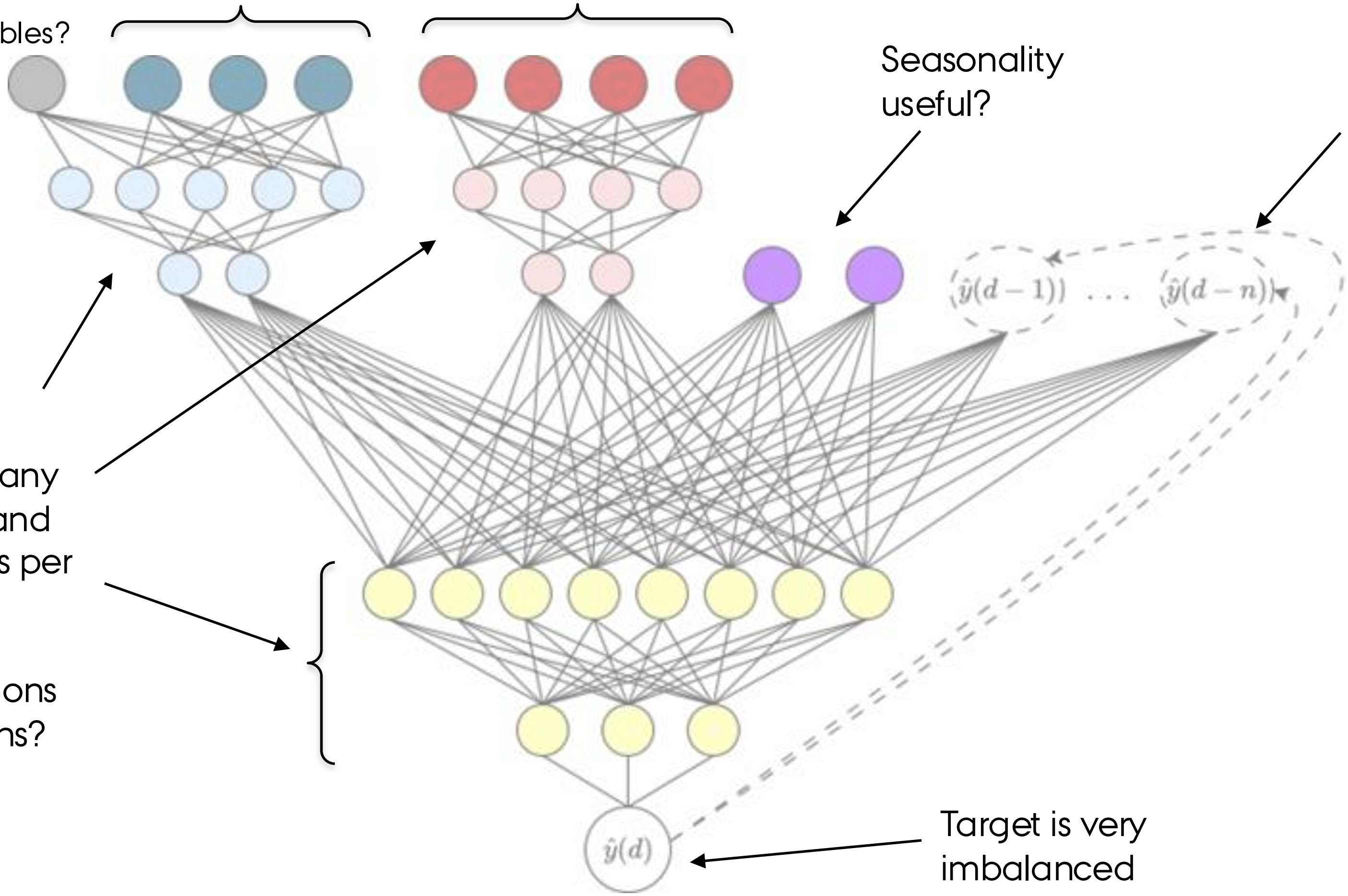
Which variables?
How many months?

Which variables?
How many days?

Some inputs are highly imbalanced and skewed;
some data seems unreasonable

Seasonality useful?

How many auto-regressive steps?



How many layers and neurons per layer?
Which activations functions?

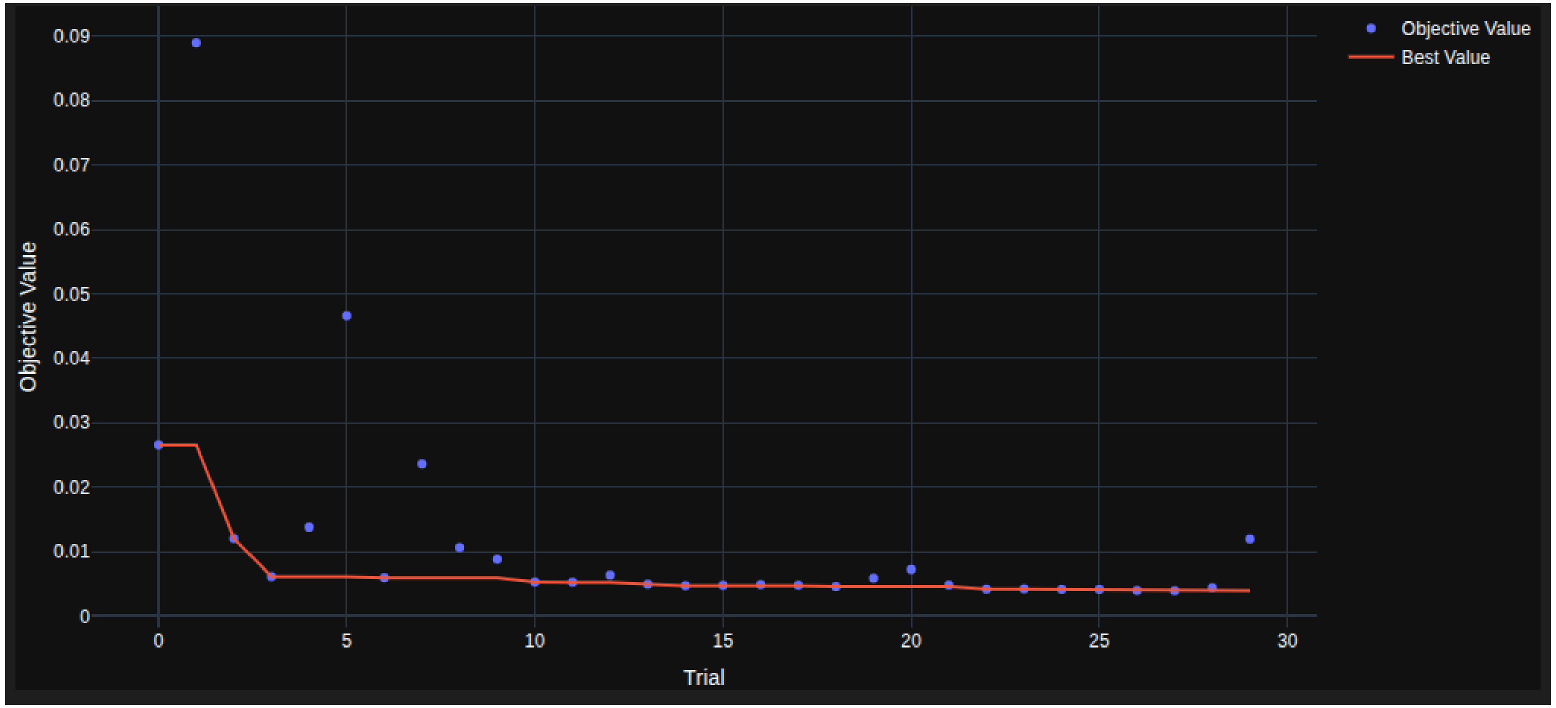
Target is very imbalanced

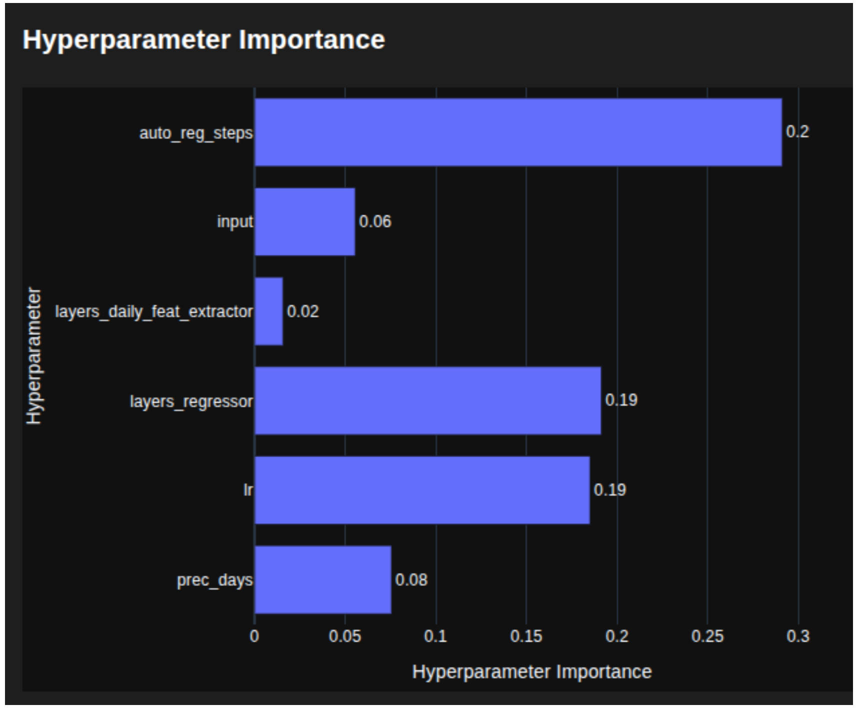
Large amount of data – need to optimize:
→ File storage
→ Data reading pipeline
→ Training loop

Zarr
EUROPEAN WEATHER CLOUD
PyTorch
OPTUNA

HYPERPARAMETER OPTIMIZATION

OPTUNA – A Framework for Hyperparameter tuning using Bayesian Optimization



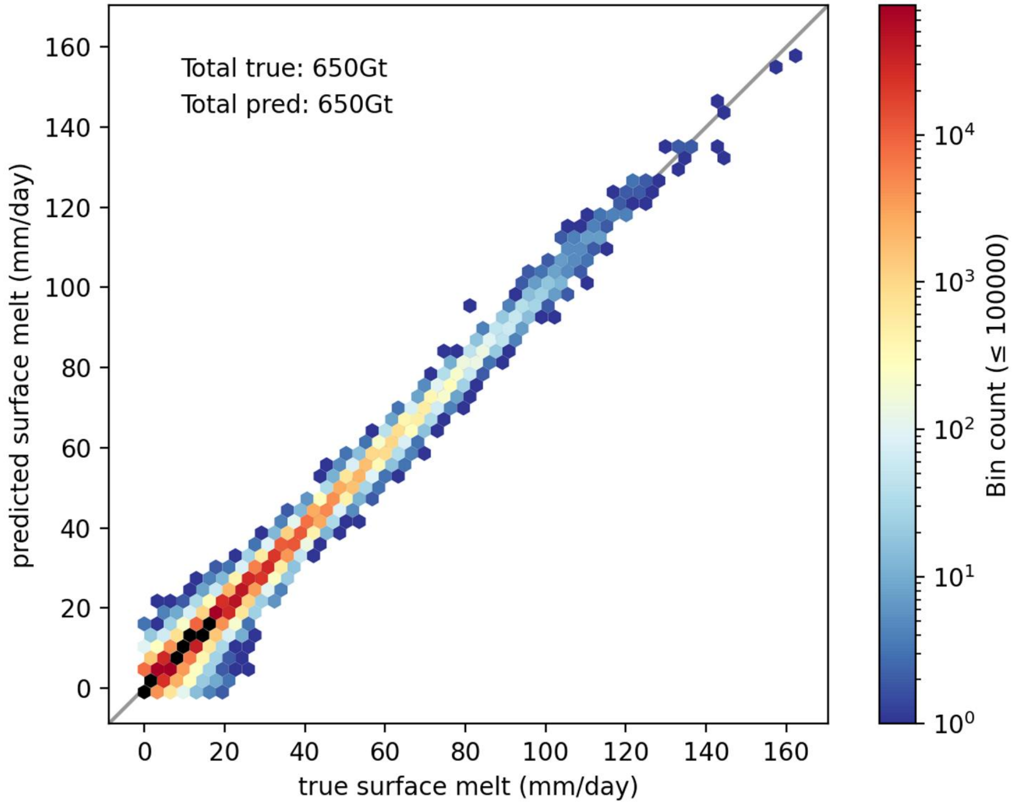


RESULTS SO FAR . . .

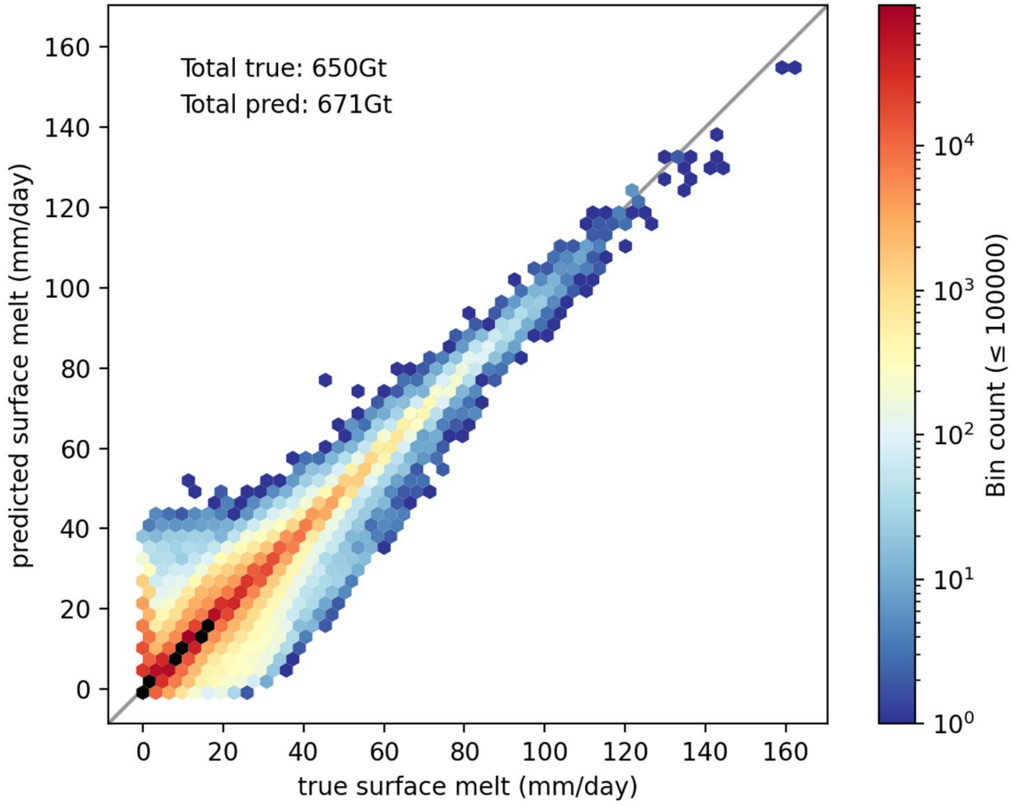
RESULTS FOR SURFACE MELT

Model with 5 days of auto-regressive steps → a lot of dependence on the previous predictions
→ error propagation

When using true previous melt:

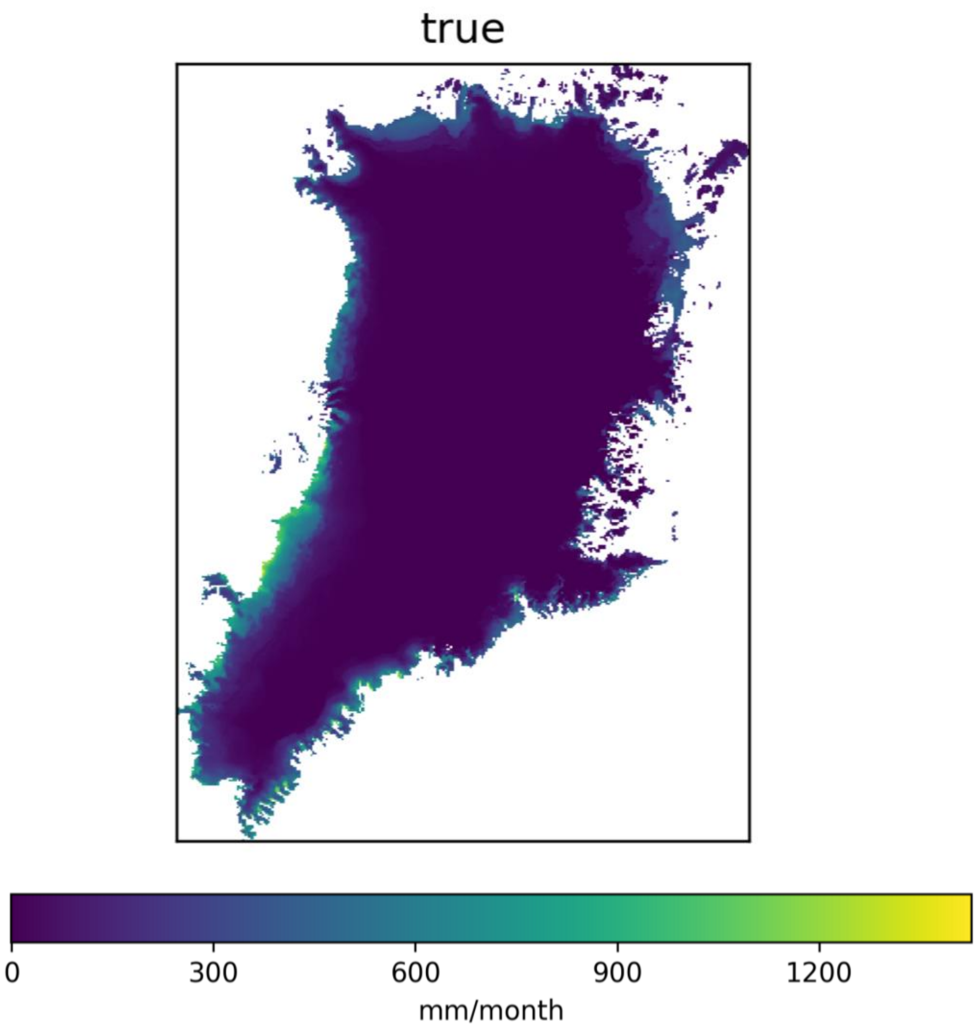


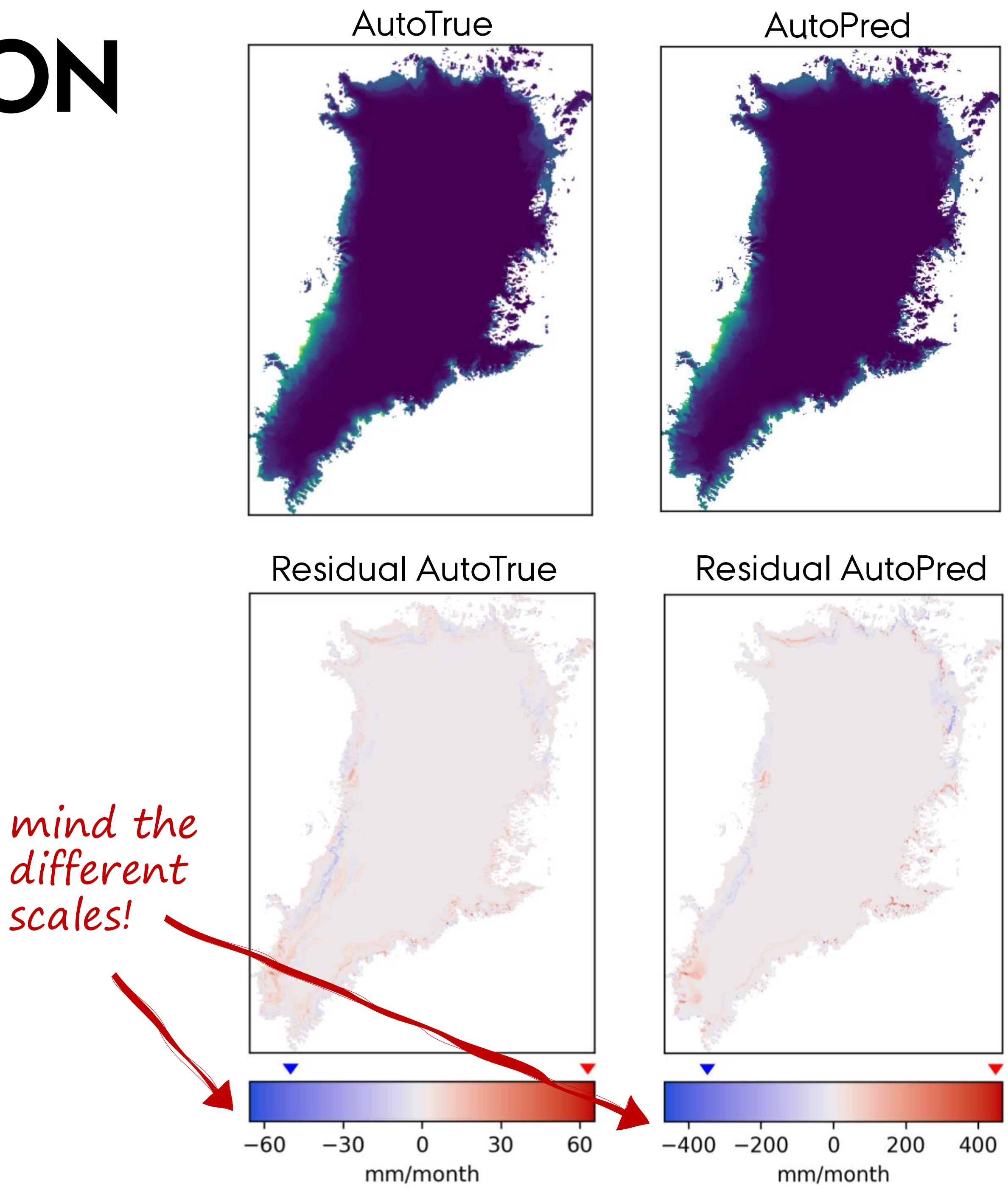
When using previous melt predictions:



ERROR-PROPAGATION

Temporal aggregation for August





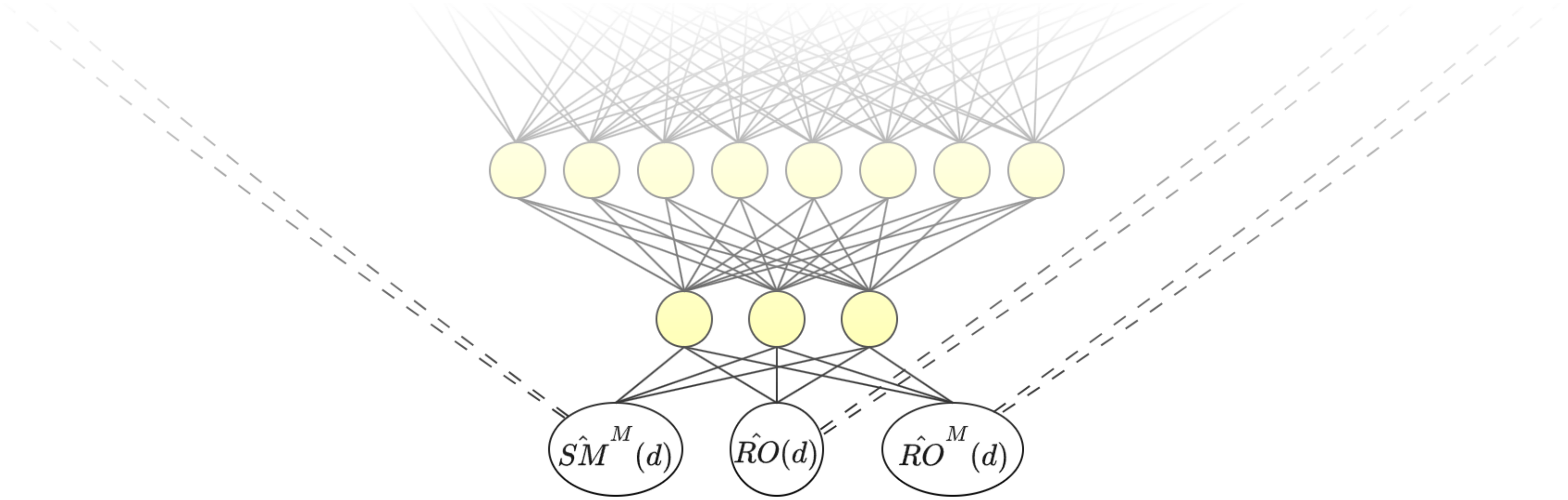
ONGOING WORK

MULTI-TARGET REGRESSION

- Predict surface melt and runoff simultaneously
- hybrid loss for classification and regression

How to choose those?

$$\mathcal{L} = \alpha \cdot BCE\left(\widehat{SM}^M, SM^M\right) + \beta \cdot MSE_{RO^M=1}\left(\widehat{RO}, RO\right) + \gamma \cdot BCE\left(\widehat{RO}^M, RO^M\right)$$



MULTI-TARGET REGRESSION

$$\mathcal{L} = \frac{1}{\sigma_1^2} \cdot BCE\left(\widehat{SM}^M, SM^M\right) + \log(\sigma_1)$$

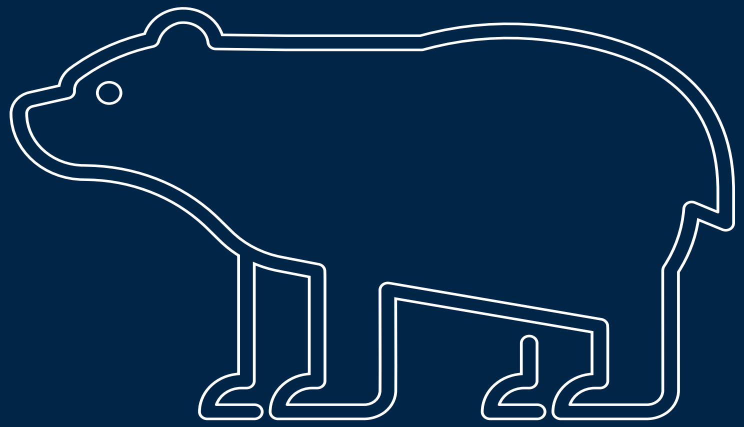
$$+ \frac{1}{2\sigma_2^2} \cdot MSE_{RO^M=1}\left(\widehat{RO}, RO\right) + \log(\sigma_2)$$

$$+ \frac{1}{\sigma_3^2} \cdot BCE\left(\widehat{RO}^M, RO^M\right) + \log(\sigma_3)$$

Using Aleatoric homoscedastic uncertainty (Kendall et al. 2018)

EVALUATION STRATEGIES

- Evaluate spatially integrated error and bias
- Evaluate per zones and basins
- Evaluate extremes
- Evaluate error propagation
- Feature Importance and Explainability ?



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